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Technical Note

THE IMPACT OF OIL SPILLS ON ARCTIC AND SUBARCTIC TERRESTRIAL ECOSYSTEMS

- A LITERATURE SURVEY -

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FORWARD

This report is the first phase of a coordinated research effort among three projects within the Earth Sciences Branch, USACRREL: "Effect on the ecology and biochemistry in cold-dominated environments of oil seepages and spills" sponsored by the Army Research Office, Life Sciences Division; "Effect of petroleum contaminants on cold regions terrain" supported by In-House Laboratory Independent Research funds; and "Degradation and erosion control for Army construction and operations in cold regions" under an Office of the Corps of Engineers work unit. Since military operations in cold regions often involve the accidental introduction of petroleum chemicals (POL) into the natural environment from pipelines, convoys, tanks, etc., information gained from these experiments will help the Army develop regulatory and advisory capabilities on terrestrial oil pollution problems.

With the information presented in this literature survey as backgroundguidance, field and laboratory experiments are planned in Alaska for the summer and winter of 1970. The experiments involved with oil and its ecological effects on the arctic and subarctic terrain will include observations on both the short-and long-term consequences of oil pollution. Long-term effects will be initially studied by surveying and describing biologically and chemically the natural oil seeps on the North Slope of Alaska.

This survey will include the description of the physical and chemical properties of the tundra soils and surface atmosphere near the seeps, the biological properties of any living plants and micro organisms under the influence of the seeps, and subsequent laboratory experiments further defining the biochemical interactions between oil and tolerant arctic organisms. Short-term effects will be investigated by producing controlled, man-made spills of different intensities and observing the response of the tundra ecosystem to the presence of petroleum pollution. Further observation of these test areas in succeeding years will provide more information as to long term damage.

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A LITERATURE SURVEY

by

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INTRODUCTION

The fact that there exists a dearth of research literature on oil spills and clean-up procedures, even for temperate marine regions, has become painfully apparent during the recent oil pollution crises. With the discovery of vast oil reserves on the North Slope of Alaska and the subsequent plans for the development of this oilfield and the proposed construction of an 800 mile pipeline extending to a southern port, this lack of knowledge becomes even more acute when considering the arctic and subarctic. This review surveys the literature on oil pollution and oil clean-up procedures and details information that may be of use in determining the effects of oil spills on the arctic and subarctic ecosystems.

The sources of information were primarily studies performed on oil spills in the marine environment which occurred from

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damaged tankers and off-shore wells (15). These studies indicate our current level of technology as well as demonstrate some of the toxic effects of raw petroleum on plant and animal life. Another source of information, especially about possible toxic components of petroleum and their effects on biological systems, was herbicide research. In both cases, the data were limited and the need for further research was apparent.

PRESENT TECHNOLOGY FOR DEALING WITH OIL POLLUTION

Some experience in handling large oil spills and the subsequent treatment of affected areas has been gained during three major oil spill incidents - the wrecks of the 'Torrey Canyon' and 'Ocean Eagle' tankers and the Santa Barbara and other recent off-shore well blow-outs. The procedures employed during each of these incidents were largely innovative, for little prior knowledge existed about appropriate oil removal methods. As a result, the clean-up attempts often caused more damage than the actual oil spill.

Natural processes if given enough time can remove a significant amount of oil from the marine environment. As much as 25% of the petroleum may evaporate as volatiles during the first few days after release (16). This loss of volatiles along with the oxidation and polymerization that occurs if the oil remains in contact with the atmosphere, results in a thickened, non-volatile

residue (17). As soon as the oil is released into the environment, biological degradation may occur by bacteria that are capable of using petroleum as a carbon source. The rate of these natural processes varies widely depending on the number and type of organisms present, the temperature, the amount of oxygen available, and the degree of dispersion of the oil. Estimates of the rate of biological decay vary greatly (4, 20), but even the highest estimates (36-350 g/cu. in. /yr) are too slow to rely on for removal of heavy oil pollution. About 15% of the total mass of oil may be persistent as asphalt (16) and resistant to further degradation.

Current treatment procedures used on oil slicks can be categorized into four types - dispersion, absorption, burning, and sinking or hiding. Since the amount of oil spilled in a major incident has been large (117,000 tons of Kuwait crude was released from the 'Torrey Canyon'; (16)), many of these techniques were tried on the same spill but often by different agencies.

Dispersion

Dispersion involves the dissipation of the oil from a water surface and into a body of water. The resulting oil globules are then more susceptible to biological attack. The dispersants that have been used are mostly non-ionic detergents consisting of a mixture of three components - a surfactant, often an ethylene

oxide derivative; an organic solvent; and a stabilizer such as coconut oil diethanolamide (14, 16). Such mixtures have been used in tremendous quantities; for example, 10,000 tons of detergents were used to treat 14,000 tons of crude oil from the 'Torrey Canyon' (16).

Several persistent problems have occurred with the use of the dispersants. After an emulsion was created, dilution by sea water could "break" the emulsion resulting in a new slick. The detergents also proved to be toxic to biological systems, expecially in areas like bays and shores where dilution was slow. The toxic factors were mostly present in the organic solvent which constituted the bulk of the detergent and contained considerable aromatics. The detergents seemed to have little effect on marine organisms when at open sea although toxicities to phytoplankton have been shown in the laboratory (13), but their use on or near shores has resulted in the death of a large range of shore organisms (5, 16). Death has been observed at 10 ppm (16, 17), but the lethal concentrations depend on many factors (toxicity to fish varies from 4 to 10,000 ppm (1). The end result of the use of such detergents on shores has been an altered ecosystem in the littoral and sublittoral regions (5). Grazing organisms, e.g. limpets, were particularly sensitive and thus after detergent treatment, large increases in kelp and other attached macrophytes occurred. This was most marked in

the littoral zone and decreased in effect as the water became deeper (5). Since such alterations in the shore ecosystems have been observed only on those oil-contaminated shores treated by detergents, the use of such chemicals seemed to create more biological damage than the oil itself.

Detergents have been used directly on beaches in an attempt to clean the oil off those areas used for recreation. However, this procedure also created problems in addition to the oil itself. Since the oil was not removed from the beach but just driven deeper into the substrate, the volume of contaminated sand was increased, subsequent removal procedures were hindered, and possibly the rate of degradation of the oil was decreased (2).

The problems observed with the use of detergents prompted the FWPCA to recommend that detergents not be used in specific areas; namely near fresh water sources, shellfish and fin fish nurseries; or on beaches of prime concern (1).

Absorption

A second method of oil clean-up is by absorption of the oil onto a removable material. Absorbents may be of many materials, both natural and man-made, but most are oleophilic and hydrophobic. The materials that have been used at least experimentally include the following (18).

ABSORBENTS

Straw
Rope
Sawdust
Bark
Ekoperl
Chrome Leather
Polyurethane Film
Polypropylene fiber
Copolymer PVC/PVA
Cotton waste
Absorbent felt paper
Waste paper
Peat
Rock wool sheets
Glass wool
Rayon floss
Sisal strings

CONGEALING AGENTS

Plastic foam
Plastic film
Nylon agglutinate

GELLING AGENTS

Molten wax
Soaps

The methods using absorption involved much labor, gave only partial removal, and thus were usually costly. However, in the future when handling efficiency for such materials is improved, absorption may develop into the method of choice because it physically removes the pollution and does not add potentially harmful chemicals.

Burning

Burning seems to be a desirable and at first glance, an easy method of removal. However, since most of the volatiles evaporate within two to three days and the oil spreads over surfaces as films which can be rapidly cooled by the underlying substrate, oil spills are usually not only difficult to ignite, but hard to keep burning. Burning the oil aboard wrecked tankers and wells, the use of torches to remove oil on beaches and rocks, and firing dry marshes and reed beds (17) may be useful on small and limited operations.

Hiding

Hiding the oil from view and thus rendering it less offensive, usually by sinking it under the water, has also been used. The French made extensive use of sinking agents during the 'Torrey Canyon' incident (16). As with absorbents, there is a wide choice of possible sinking or hiding agents (18):

Sand	Silicone mixtures
Fly ash	Carbonized sand
Cement	Vermiculite
Brickdust	Crushed stone
China clay	Slacked lime
Volcanic ash	Stucco

At sea and in estuaries and swamps, the oil may sink as a mat and coat the bottom. Such a condition may creat adverse

biological conditions, but research in this area is almost entirely lacking.

PETROLEUM PRODUCT TOXICITY

Although little research has been performed on the toxic components of petroleum, especially raw petroleum, studies have shown that oil itself may be toxic. Of course, the saturation of an organism with petroleum will have a marked indirect effect on metabolism. For example, waterfowl that have had their feathers saturated with oil are often observed to die rapidly when exposed to subzero temperatures. This was shown to be the indirect effect of increased heat conductivity of the plumage as a result of the oiling. The birds were forced to respire at much greater rates than normal in order to maintain body temperatures and thus used their fat reserves so rapidly that eventually they died of starvation (10).

Oil may also be directly toxic to organisms. As waterfowl clean their plumage, they ingest large quantities of oil which may be expected to have a range of adverse effects. Industrial oils have been shown to be toxic to waterfowl and the ingestion of such oils has resulted in a number of physiological disorders (11). However, again conclusive data on the toxicity of raw petroleum is lacking.

Herbicide specialists have long been interested in petroleum oils because of their phytotoxicity. Generally, aromatics are the most phytotoxic, paraffins the least, with the napthylenes and olefins intermediate. The smaller molecules in each group are the most toxic, however, the system in which the compounds are suspended can be quite important. In the benzene, cyclohexene, cyclohexane, hexane and hexene series, the toxicity of hexene was one-third that of benzene if in a vapor/air system, but hexene was 11 times as phytotoxic as benzene when in a water/oil system (8). The hydrocarbons may become more toxic when oxidized, probably because of the acids created during oxidation (19). Changes in the cellular permeability are apparent after treatment with the toxic hydrocarbons and such changes probably result from a solubolization effect on membrane lipids.

Current indications are that some of the hydrocarbons in oil, particularly those that are chlorinated and have closed rings, are not degraded in marine systems (3). These compounds do not occur naturally and no bacteria seem to have evolved to degrade them. Of even greater importance to biological systems is the fact that compounds such as these are often concentrated in the fatty tissues of organisms and thus present an increasing hazard as the trophic level becomes higher.

APPLICATIONS TO TERRESTRIAL ARCTIC AND SUBARCTIC ENVIRONMENTS

In the absence of studies directly concerned with the effects of oil contamination and subsequent clean-up procedures on arctic ecosystems, only implications and generalizations can be discussed. However, by combining the data learned from the research in the temperate and marine regions with known characteristics of arctic and subarctic ecosystems, some problems become apparent.

Since the heat balance of the arctic is an extremely important factor for stability of the tundra (6) oil spilled on the tundra landscape may be expected to cause a severe local perturbation in heat flux. Destruction of the stabilizing vegetative mat in addition to increased absorption of solar radiation as a result of oil spills may quickly create increased thaw and permafrost degradation. The scope of the toxic effects of oil spilled on the tundra vegetation and into the fresh water streams cannot be accurately predicted because of the complete lack of supporting data.

Since the differences among plants in susceptibility to toxic oils have in some cases overshadowed the differences in the toxicities of the hydrocarbons (8), the introduction of oil onto the tundra might be expected to affect some species much more

severely than others. The fact that a hardened pitch reportedly underlies the tundra for a much as 1200 feet near natural oil seeps in northern Alaska (7, 9, 12) indicates that a least some arctic organisms may be able to tolerate the presence of petroleum. However, considering the potential abrupt changes in microclimate that may occur from oil pollution and the inherent slow recovery rate of arctic ecosystems, the natural development of a vegetative mat of oil tolerant plants over polluted areas may be unimportant or non-existent. Therefore, it becomes critical to develop efficient techniques of oil removal and subsequent revegetation.

Most of the currently available clean-up procedures will be difficult to apply to the arctic terrain. The use of dispersants, because of the toxicity and the effect of driving the oil deeper into the substrate, will likely be of limited value since their use only complicates the pollution problem. At the very least, detergent use may result in a completely altered ecosystem as was observed on treated shores (5). Burning may be feasible since the wet organic tundra mat may hold the oil near the surface and thus provide a convenient means of oil removal. However, since the mat is usually saturated with water, it may have to be dried before burning. Of even greater importance are the problems that will be

created by removal of the insulating vegetative mat which plays an intricate role in the thermal stability of tundra soils. It has been shown that disturbance by fire increased the depth of thaw over permafrost by as much as 20% the first summer and as much as 60% in following years (6).

As a stopgap measure to allow time for the mobilization of forces to clean-up the oil, various non-toxic hiding and absorbing agents might be applied to the spill to both prevent its spread and to decrease the contamination of wildlife. It seems particularly important to protect fowl considering the relationship between plummage oiling and death in cold environments (10).

Considering not only the recent oil discoveries in Alaska but also various complex military operations such as the U.S. Army's Haines-Fairbanks petroleum pipeline, the occurrance of oil spills on the arctic and subarctic terrain are highly probable. The importance of each spill will be dictated by its location. Those in the vicinity of concentrations of wildlife and near fresh water supplies are potentially disasterous. The obvious best course of action is to develop an efficient technology in oil pollution control prior to the occurrance of any major oil pollution incident in the arctic. In any case, we should not create more destruction in haphazard and unadpted clean-up attempts than would have occurred had we just left the oil alone.

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